Application of Seismic Methods for Fracture Characterization

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RESEARCH OBJECTIVES

A five-year (2000–2004), comprehensive, joint industry, university, and national laboratories project was carried out to develop and apply multiscale seismic methods for detecting and quantifying fractures in naturally fractured gas reservoirs.

APPROACH

This project took place within a 20-square-mile area at a producing gas field in the northwest part of the San Juan Basin in New Mexico. Three-dimensional surface seismic, multi-offset 9-C vertical seismic profiling (VSP), 3-C single-well seismic, and well-logging data were complemented by geologic/core studies to model, process, and interpret the data. The overall objective was to determine the seismic methods most useful in mapping productive gas zones.

ACCOMPLISHMENTS

Data from nearby outcrops, cores, and wellbore image logs suggested that natural fractures were probably numerous in the subsurface reservoirs at the site selected, and trend north-northeast/south-southwest despite the apparent dearth of fracturing observed in the wells logged at the site (Newberry and Moore wells). Estimated fracture spacing is on the order of 1–5 m in Mesaverde sandstones, less in Dakota sandstones. Fractures are also more frequent along fault zones, which in nearby areas trend between north-northeast/south-southwest and northeast-southwest—and are probably spaced a mile or two apart. The maximum *in situ* horizontal, compressive stress in the vicinity of the seismic test site trends approximately north-northeast/south-southwest. The data are few, but they are consistent.

The seismic data present a much more complicated picture of the subsurface structure. Faulting inferred from surface seismic had a general trend of SW–NE, but with varying dip, strike, and spacing. Studies of P-wave anisotropy from surface seismic showed some evidence that the data did have indications of anisotropy in time and amplitude. However, compared to the production patterns, there is little correlation with P-wave anisotropy. One conclusion is that the surface seismic reflection data are not detecting the complexity of fracturing controlling the production. Conclusions from the P-wave VSP studies showed a definite 3-D heterogeneity in both P- and S-wave characteristics. The analysis of shear-wave splitting from 3-D VSP data gave insight into the anisotropy structure with depth around the borehole. In the reservoir, the VSP shear-wave splitting data do not provide sufficient constraints against a model of lower symmetry than orthorhombic, so that the existence of more than one fracture set must be considered. It was also demonstrated that vertical transverse isotropy (VTI) and orthorhombic symmetry could be well defined from the field data by analyzing shear-wave splitting patterns. The detection of shear-wave singularities provides clear constraints to distinguish between different symmetry systems. The P-wave VSP common-depth-point (CDP) data showed evidence of fault detection at a smaller scale than the surface seismic showed, and in directions consistent with a complicated stress and fracture pattern. The single-well data indicated zones of anomalous wave amplitude that correlated well with high gas shows. The high amplitude single-well seismic data could not be explained by wellbore artifacts, nor could it be explained by known seismic behavior in fractured zones. Geomechanical and full-wave elastic modeling in 2- and 3-D provided results consistent with a complicated stress distribution induced by the interaction of the known regional stress and faults mapped with seismic methods.

SIGNIFICANCE OF FINDINGS

Sophisticated modeling capability was found to be a critical component in quantifying fractures through seismic data. Combining the results with the historical production data showed that the surface seismic analysis provided a broad picture consistent with production, but not detailed enough to consistently map complex structuring, which would allow accurate well placement. VSP and borehole methods show considerable promise in mapping the scale of fracturing necessary for more successful well placement. Integration of these methods at one field site enables investigators to give specific recommendations for the scale at which each method and fracture complexity would be appropriate.

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